Comparison of Present Day and Historical Dispersal Patterns in the Western Adriatic

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LONG-TERM GOALS

By improving numerical representations of coastal circulation, sediment properties, and wave fields, this project seeks to develop reliable predictions of sediment concentration, transport and deposition. Calculations that simulate conditions during field experiments can be validated using observations. We can then extrapolate to longer timescales by running longer simulations, and by predicting dispersal patterns under configurations that represent past geologic or climatologic conditions. By using a well-tested model to evaluate the impact that shifts in sediment and freshwater delivery have had on seafloor texture, we hope to bridge the gap between present day observations and the events and climatic shifts capable of leaving a stratigraphic signal.

OBJECTIVES

Sediment delivery, flux, and deposition are quantified within a three-dimensional hydrodynamic model that links sediment transport in the western Adriatic Sea to deposition. The study is evaluating sediment dispersal in the Adriatic under different wind regimes: the Bora winds are storm winds that blow from the northeast, and the Sirocco winds tend to be less energetic, but are directed up the axis of the Adriatic from the southeast. The largest point source of sediment within the Adriatic is the Po River, but dispersal in that region is poorly resolved in our current model. This has motivated focus on the Po delta that will evaluate competing hypothesis for sediment dispersal and delta progradation there. Dispersal mechanisms operating on the modern Adriatic may be fundamentally different than those of the paleo-Adriatic due to the likely absence of strong coastal currents under lowered sea level. This is tested by comparing transport patterns of the modern Adriatic to those predicted for the Adriatic during conditions representative of the last glacial maximum (LGM).

APPROACH

We use a series of linked models as a platform for quantifying sediment transport in the coastal ocean. The representation of the Adriatic Sea (see figure 1) has been developed by our group at VIMS in collaboration with scientists at the US Geological Survey (Chris Sherwood, Rich Signell, and John Warner) and at NRL (Julie Pullen). We have used two numerical models: NCOM (the Navy Coastal Ocean Model, see Martin, 2000, Pullen, *et al.* 2003), and ROMS (the Regional Ocean Modeling System, see Haidvogel and Beckman, 1999, Sherwood, *et al.* in press). Recent efforts have focused on

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the ROMS model, because it has been linked to the SWAN model (Shallow WAves Nearshore; see Booij, *et al.* 1999) by Sherwood and Signell.

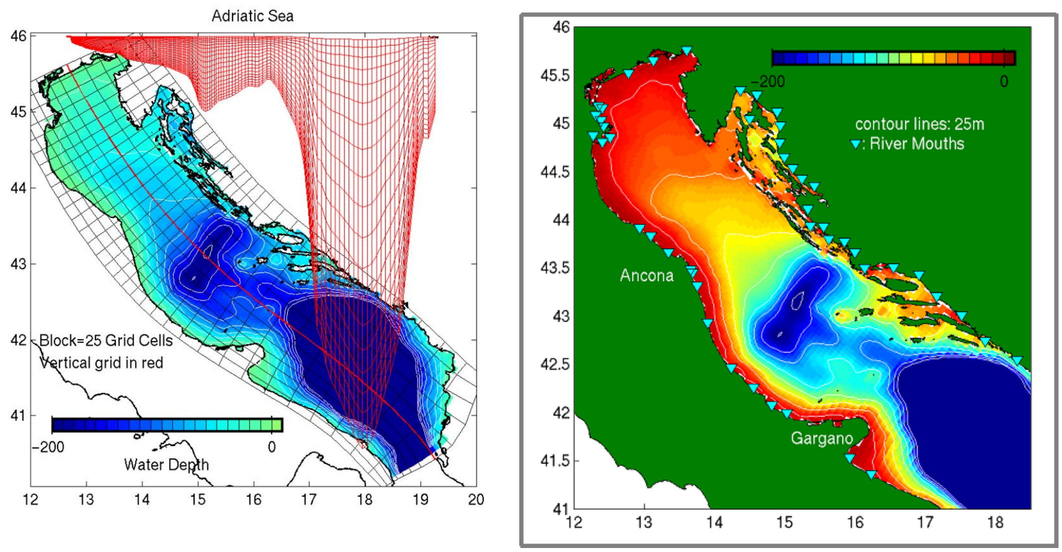

Figure 1: Adriatic Sea, showing (A) bathymetry and model grid, and (B) location of freshwater sources represented within calculations, and the locations of Ancona and the Gargano Peninsula.

Two systems are being considered. First, we study the modern Adriatic, for which our colleagues have a rich data set to classify both seafloor properties and water column sediment transport. Particular attention is being focused on the Po delta region. Secondly, a related study seeks to quantify dispersal patterns of paleo-Po River sediment under conditions representative of the last glacial maximum (LGM), 18,000 years before present, when sea levels were 120 m lower.

The Adriatic Sea is an excellent test bed for this effort because, for modern conditions, there is an ideal data set available from the 2002/2003 EuroStrataform and ACE programs and hydrodynamic models have been implemented successfully for this time. Winds are specified using predictions from two atmospheric models: the 4km-resolution Naval Research Laboratories COAMPS™ model (Coupled Ocean Atmospheric Mesoscale Prediction System; see Hodur, 1997; Hodur, *et al.* 2001); and the 7 km predictions of the Bologna Limited Area Model (BoLAM; see http://www.cmirl.ge.infn.it/MAP/BOLAM/Bolamin.htm). There is also evidence for large modifications to sediment delivery mechanisms over geologic timescales.

Sediment transport routines developed for ROMS allow input from fluvial sources and exchange between suspended and sea-floor sediment. Sediment is transported by settling, advective currents, and turbulent diffusion. Multiple grain types are used to track changes to seabed texture and differential transport of material. Input fields for freshwater and sediment are difficult to prescribe, because within the study area only the Po, Pescara, and Biferno rivers are gauged. While previous studies provide some guidance for freshwater input (i.e. Raicich, 1994, 1996), and erosion potential (i.e. Aquater, 1982), these are monthly averages at best. We use a combination of gauged and climatic data with sediment rating curves from Kettner and Syvitski (in review) and Syvitski and Kettner (in review) to specify freshwater and sediment inputs for 2002/2003.

WORK COMPLETED

During 2004, we improved our representation of the coastal Adriatic in several ways. Switching platforms from NCOM to ROMS was a major emphasis, and included porting improvements that had been built into the NCOM effort. Towards this, we revised the model grid based on updated bathymetric data (see Corregiari, *et al.* 1996), so that the ROMS model includes shallow areas (up to 5m depth) that overlap with measurements. We updated inputs to include the best data available for each fluvial source of freshwater and sediment. We added 23 rivers to the model, estimating freshwater discharge following Raichich (1994, 1996), and sediment discharge following guidance from Hydrotrend simulations (see Syvitski, *et al.* 1998; Kettner and Syvitski, submitted; Syvitski and Kettner, submitted). Discharge of the Po, Pescara, and Biferno Rivers are specified using daily averaged values from the Italian Hydrographic Office. Fluvial sediment was specified to be primarily flocculated material from the Po and unflocculated material from Apennine rivers, following Fox, *et al.* (2004). Sources of freshwater from along the Croatian coast were added to include groundwater discharge noted by Raicich (1994, 1996). These changes result in both better resolution of the Western Adriatic Coastal Current (WACC), and improved ability to estimate sediment budgets for the 2002/2003 season.

Simulations to date have focused on representing the entire Adriatic Sea using the model grid shown in figure 1A. This provides coarse resolution predictions of dispersal within the Po delta region, and most sediment is deposited within a few grid cells of the river mouth. Comparing predictions to field observations of water column transport and seabed deposition have been problematic, and the model can not test competing hypothesis for progradation of the Po delta. To address this, A. Bever (MS student, VIMS) is developing a nested ½ km resolution model for the Po delta. This will be used to evaluate the roles that initial deposition, wave resuspension and gravity flows play in progradation of the Po delta during observed floods.

A simulation of the Adriatic during LGM (figure 2) is being compared with the modern system. This evaluates the influence of changes in basin shape on dispersal patterns by predicting transport under conditions of steady freshwater and sediment input. The influence of climatic shifts in wind and temperature fields is neglected, but may be the subject of later work. Following Kettner and Syvitski (submitted) discharge from the Po River is assumed to increase during LGM, because the paleo Po captured smaller neighboring rivers. This simulation uses the modern wind field to preserve small scale variability, because studies of the modern Adriatic have shown the importance of this in driving the coastal current (Pullen, *et al.* 2003). Future work hopes to examine the robustness of our conclusions under a variety of forcing wind fields.

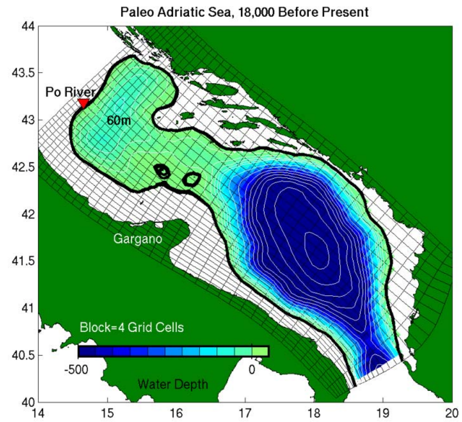

Figure 2: Grid used to represent Adriatic during Last Glacial Maximum (LGM). The paleo-Po river empties into the northern part of the basin. Each grid cell shown represents 25 model grid cells. The present day coastline is shown in green. Our estimate of the LGM coastline is drawn in black.

Calculations assume that the initial sea bed is uniformly mixed sands and fines. Fines are either flocculated, (settling at 1.0 mm/s) or unflocculated (settling at 0.1 mm/s). This approach neglects both size grading present in the Adriatic, and bed consolidation on the muddy beds. Chris Sherwood is providing an initial bed that has been interpolated from available sediment data. A bed consolidation routine is being investigated to supplement the bed armoring code now implemented in the seabed model. The model presently follows Harris and Wiberg (2001, 2002) by limiting erosion of each sediment class during any timestep to the amount of that type in the active layer of the bed. A model that assumes that entrainment of the bed is limited by depth-dependent cohesive properties of the bed (i.e. Sanford and Maa, 2001) is being added.

RESULTS

Results completed using river and wind forcing from September, 2002 – May, 2003 imply that dispersal of fluvially delivered sediment depends to the first order on sediment settling characteristics, and secondarily to wave energy and circulation patterns. The direction of dispersal is dependent on wind- and buoyancy driven currents and dominated by transport within the WACC during strong Bora winds (figure 3).

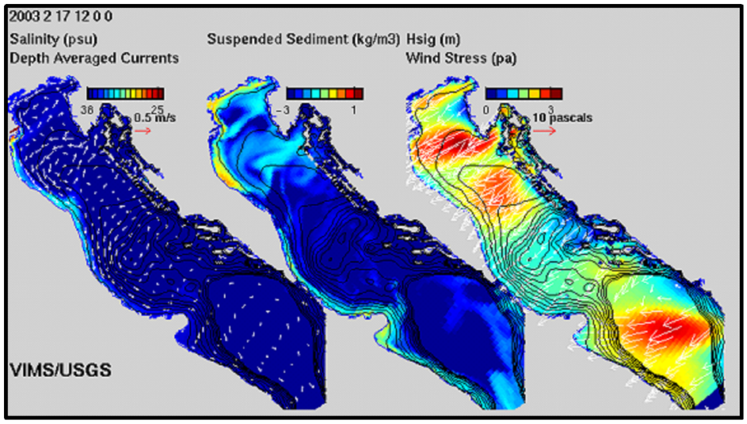

Figure 3: Currents and sediment concentrations driven by winds, buoyancy, and waves, representing February 17, 2003, a time of Bora winds. Left panel shows depth-averaged current, and the Po plume hugging the coast. Middle panel shows suspended sediment, dominated by wave resuspension. Winds and waves predicted by LAMI and SWAN models are shown in rightmost panel.

Sediment that is packaged as flocculated material is predicted to rapidly settle to the seafloor within 10 km of the Po river mouth. Material delivered as unflocculated sediment is much more widely dispersed. Sediment dispersal is maximized under conditions of strong winds from the northeast, termed "Bora" winds, which intensify the WACC (figure 4A). Southeasterly Sirocco winds tend to be upwelling favorable, and weaken currents in the western Adriatic, thereby reducing sediment flux (figure 4B). Net transport under both Bora and Sirocco winds is towards the south.

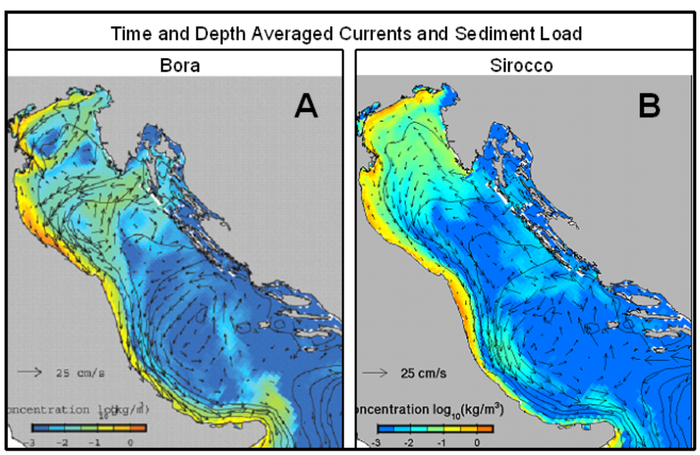

Figure 4: Depth averaged suspended sediment concentrations (color scale) and current velocities (arrows) time averaged for a Bora (February 15—20, 2003) and a Sirroco event (November 14—19, 2002). Bora enhances the coastal current and increases suspended sediment concentrations relative to Sirocco forcing.

Predictions for the Adriatic under conditions of lowered sea level imply that sediment from the Po River has likely experienced a dramatic shift in dispersal patterns over the Holocene. Preliminary results indicate that during the LGM, sediment from the Po River would have been deposited directly into the offshore basin, and not dispersed along coast (figure 5). Current velocities along the western edge of the paleo Adriatic are predicted to be significantly smaller than those of the modern Adriatic, in part because the Bora winds that drive the modern WACC are most energetic north of Ancona (see figure 3) and therefore do not impact coastal circulation under conditions of lowered sea level. Sediment from the Po therefore tends to remain closer to the river mouth, even when sediment is modeled as slowly settling material (figure 5).

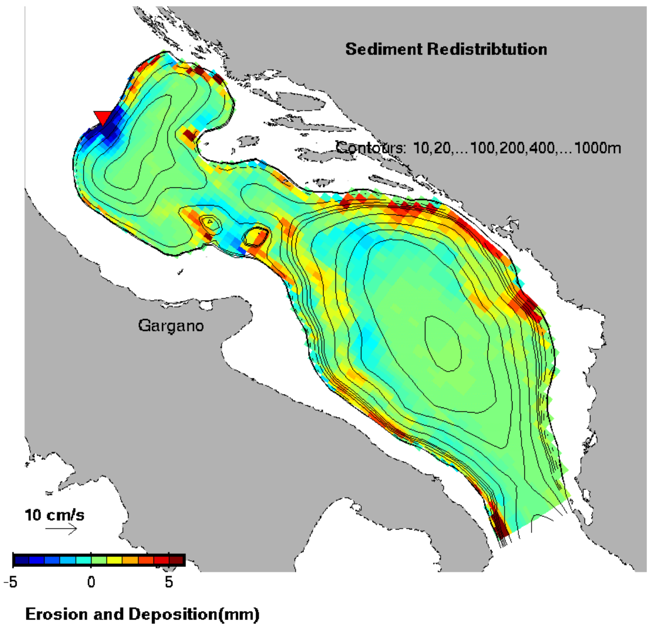

Figure 5: Predicted erosion (red) and deposition (blue) for a 75 day simulation of the Adriatic at LGM. Dispersal distances for sediment from the Po are much lower here than is seen in the modern Adriatic, even though the sediment was modeled to be slowly settling fine grained material.

IMPACT/APPLICATIONS

Several components of this work are of interest to EuroStrataform and other colleagues. The gridded bathymetry, for example, has been supplied to several other P.I.s. Improved estimates of sediment and freshwater delivery during the 2002 / 2003 fall and winter season will better constrain our estimates of sediment budgets during this time. Both physical oceanographers interested in dense water formation in the modern Adriatic, and stratigraphic modelers have requested copies of our model results. We hope to continue to work with Patricia Wiberg (U.Va.) in developing a robust bed armoring and bed consolidation model that is suitable for inclusion in three dimensional models and that compares well against available data. Our emphasis on the Po delta region also promises to bridge a gap between the three dimensional modeling effort and seabed and tripod observations of the Po delta region conducted by researchers at Oregon State, University of Washington, and WHOI.

RELATED PROJECTS

This year, methods for predicting sediment dispersal and deposition on the Eel River shelf, northern California were refined. Two mechanisms for sediment transport (dilute suspension and near-bed wave dominated gravity flows) have been identified on this energetic, flood-dominated shelf. We included both of these mechanisms in a three-dimensional sigma-coordinate model (Harris, *et al.* 2004). Approximately 30% of sediment delivered to the coastal ocean by floods of the Eel River is retained in mid-shelf muds and inner shelf sands (Sommerfield and Nittrouer, 1999; Wheatcroft and Borgeld, 2000; Crockett and Nittrouer, 2004). Using our three-dimensional model, we conclude that about 20% of the sediment delivered is transported north of the shelf by wind-forced ocean currents, and the remaining sediment is spread as a thin, widely-dispersed drape (Harris, *et al.* in review). The cross-shelf location of a flood deposit is sensitive to wave energy, but the volume of the flood deposit depends critically on partitioning of sediment into aggregated particles and disaggregated single grains (Harris, *et al.* in review). Related to this study, I have contributed towards two chapters of a volume on continental-margin sedimentation (Syvitski, *et al.* in revision; Wheatcroft,*et al.* in review).

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